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RESEARCH MEMORANDUM

DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A VERTICALLY RISING AIRPLANE MODEL IN HOVERING FLIGHT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A VERTICALLY RISING AIRPLANE MODEL IN HOVERING FLIGHT

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SUMMARY

An investigation is being made to determine the stability and control characteristics of a vertically rising airplane model. This paper presents the results of some preliminary hovering flight tests made in still air, away from the interference effects of the ground and side walls, and with normal airplane-type controls operating in the slipstream. The investigation included tests with two center-of-gravity positions, 0-percent and 45-percent mean aerodynamic chord.

The uncontrolled pitching motion (motion about spanwise axis) consisted primarily of an unstable oscillation which was more unstable with the rearward than with the forward center-of-gravity location. The period of this pitching oscillation for the full-scale airplane would be about 10 seconds. The uncontrolled yawing motion (motion about an axis normal to the plane of the wing) was about neutrally stable and was predominantly aperiodic (nonoscillatory). The controllability of the model was satisfactory and the model could be flown smoothly and easily under the conditions of the tests despite the lack of stability. The model was difficult to trim in hovering flight because of random trim changes, one cause of which was the rather large random fluctuations in moments caused by propeller operation. These moment fluctuations were observed in preliminary force tests of the model in the static-thrust conditon.

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INTRODUCTION

An investigation is being conducted to determine the stability and control characteristics in hovering flight of a vertically rising airplane model. This investigation is being conducted in the facility used by the Free-Flight-Tunnel Section for flight testing hovering models by the trailing-flight-cable technique.

The flying model was essentially a conventional airplane model with a large dual-rotating propeller and sufficient power to take-off and land vertically. The model had a rectangular wing and a cruciform tail with rectangular surfaces and was controlled by conventional airplane control surfaces operating in the propeller slipstream.

The part of the investigation completed to date consists of hovering flights in still air made with two center-of-gravity positions, 0- and 45-percent mean aerodynamic chord. The stability of the model was determined quantitatively from motion-picture records of flights and the controllability and general flight behavior of the model were determined qualitatively from the pilot's observations.

NOMENCLATURE AND SYMBOLS

Since the present model and tests represent an airplane in a very unusual flight condition, there is little precedent with regard to nomenclature, axes, or symbols. The conventional airplane-type body system of axes has been selected for use in the present paper. The body axes are an orthogonal system with the origin at the center of gravity in which the X-axis (fuselage axis) is parallel to the thrust line, the Z-axis (normal axis) is in the plane of symmetry and perpendicular to the X-axis, and the Y-axis (spanwise axis) is perpendicular to the XZ-plane. A sketch showing these axes is presented in figure 1.

For convenience in discussion, the motions along the axes are referred to by the terms commonly used with regard to airplanes in the normal flight regime; that is, motions along the fuselage axis (X-axis) are referred to as longitudinal motions, motions along the spanwise axis (Y-axis) are referred to as lateral motions, and the motions along the normal axis (Z-axis) are referred to as normal motions. The angular motions about the axes are also referred to by the terms commonly used with regard to the airplane in the normal-flight regime; that is, motions about the fuselage axis (X-axis) are referred to as rolling, motions about the spanwise axis (Y-axis) are referred to as pitching, and motions about the normal axis (Z-axis) are referred to as yawing. In accordance with the policy of treating the model as a conventional airplane model, the control surfaces are also referred to by the terms commonly used with regard to airplanes in normal flight; that is, the differentially moving controls on the wings for providing roll control are called ailerons, the control surfaces on the tail in the same plane as the wing are called elevators, and those on the tail perpendicular to the plane of the wing are called rudders.

The definitions of the symbols used in the present paper are as follows:

y	displacement along Y-axis, feet
z	displacement along Z-axis, feet
θ	angle of pitch, degrees
ϕ	angle of bank, degrees
ψ	angle of yaw, degrees

MODEL

The model was a conventional airplane configuration having an eight-blade dual-rotating fixed-pitch propeller in a tractor arrangement, a rectangular wing, and a cruciform tail with rectangular surfaces. The geometric characteristics of the model are presented in table I. Photographs of the model are presented in figure 2 and a sketch of the model is shown in figure 3. The model was powered by a 5-horsepower variable-frequency electric motor, the speed of which was changed to vary the thrust.

The model was controlled by conventional control surfaces operating in the propeller slipstream. The ailerons were controlled automatically by a displacement-type autopilot which kept the model oriented in roll with respect to the pilot's position. The model was maneuvered by the elevator and rudder controls which were remotely controlled by the pilot. The control surfaces were actuated by flicker-type (full on, full off) pneumatic servos which were controlled by electric solenoids.

The power for the motor and electric solenoids and the air for the servomechanisms were supplied through wires and plastic tubes which trailed from the tail of the model.

TEST EQUIPMENT AND TECHNIQUE

The investigation is being conducted in the facility used by the Free-Flight-Tunnel Section for flight testing hovering models by the trailing-flight-cable technique. This facility consists of a 24-foot-square open-top cage 15 feet high which is located in a large building that provides protection from outside turbulence. The purpose of this cage is to provide protection for the operators and observers without causing interference with the natural circulation produced by the slip-stream. A sketch of the test area with the model and the operators in position is shown in figure 4.

A safety rope (see fig. 4) suspended from above is attached to the propeller hub by means of a swivel joint to prevent crashes in case of a power failure or control malfunction. During flight the rope is kept slack so that it does not appreciably influence the motions of the model. In order to insure that the rope is really slack, several feet of the rope are allowed to lie on top of a guard mounted in front of the propeller. This propeller guard (shown in fig. 2) is constructed primarily of $\frac{1}{8}$-inch aluminum tubing and string.

The reference for the simple displacement-type autopilot used to control the ailerons is a string from the autopilot pickoff to the wall of the building. As shown in figure 4, this spring runs through a pulley on the wall and has a small weight tied to the free end to maintain a small constant tension in the string. The small constant force exerted by this weight does not affect the stability of the model but does produce a small out-of-trim moment which is easily compensated by adjusting the trim setting of the proper control.

The elevator and rudder are remotely controlled by the pilot by means of two small control sticks on his control box. One of these sticks operates the elevator and the other operates the rudder. In flying the model, the pilot operates one of these control sticks with each hand. Two operators in addition to the pilot are required for flying the model: one to control the power to the propeller and one to control the safety rope. The pilot and power operator are the principal observers because they have control of the model and can obtain qualitative indications of the stability and control characteristics. Movie cameras are placed in advantageous locations for obtaining quantitative data on the stability of the model and its response to control movements.

The speed of the model motor was controlled by the frequency of the current supplied to the motor. This change in frequency was accomplished by varying the speed of an alternating-current generator by controlling the power supply of its direct-current driving motor. Since these units were standard heavy-duty pieces of equipment (5-horsepower motor and 20-horsepower generator) the time required for these units to change speed plus the time required for the model motor to change speed introduced considerable time lag in the control of the thrust of the model.

The flight technique will be explained by describing a typical flight. The model hangs on a safety rope and the power is increased until the model climbs to the desired altitude. The safety rope is allowed to coil on top of the propeller guard and the rope operator then recovers any excess slack or releases more rope as required during the flight. During the flight the power is regulated to keep the model at the desired altitude. The pilot keeps the model as near the center of the test area as possible during the climb and until the model is in a steady hovering condition; then he performs the maneuvers required for the particular tests and observes the stability and control characteristics.

In order to determine the stability of the model it is allowed to fly uncontrolled for as long as possible starting from as near a steady hovering flight condition as can be obtained. The pilot establishes this steady hovering condition by trimming the controls carefully and controlling the model until it appears perfectly still and erect. He then leaves the controls fixed in the trim position until the model moves off too far from the center of the test area and is in danger of striking the walls of the cage or some other obstruction. Motion-picture records of these uncontrolled motions are made. This maneuver is only satisfactory for determining the stability of unstable or lightly damped motions. For heavily damped motions, the uncontrolled motions can be recorded after the controls have been abruptly deflected to start a motion and return to the trim position.

TESTS

Flight tests were made with center-of-gravity locations of 0 percent and 45 percent of the mean aerodynamic chord. The stability of the uncontrolled motions of the model was determined from time histories of the motions obtained from motion-picture records. The controllability and the general flight behavior of the model were determined qualitatively from the pilot's observations. General flight behavior is the term used to describe the over-all flying characteristics of a model and indicates the ease with which the model can be flown. In effect, the general flight behavior is much the same as the pilot's opinion of the flying qualities of an airplane and indicates whether stability and controllability are properly proportioned.

RESULTS AND DISCUSSION

The results of the tests for the two center-of-gravity locations are presented in figures 5 and 6 which show the uncontrolled pitching and yawing motions, respectively. The time histories of figures 5 and 6 are not symmetrical about the horizontal axis because the model could not be trimmed perfectly. Since the control surfaces were not perfectly trimmed, the model moved away from the center of the test area, and its characteristic motion was superimposed on the motion caused by the out-of-trim moments.

The time histories presented in figure 5 indicate that the model had an unstable pitching oscillation for both center-of-gravity locations and that this oscillation was more unstable for the rearward than for the forward location. Approximate values for the period and time to double amplitude for the model and the corresponding scaled-up values for the airplane are presented in the following table:

Factor	Model		Airplane	
	Center-of-gravity location		Center-of-gravity location	
	Forward	Rearward	Forward	Rearward
Time to double amplitude, sec	5.5	3.0	14.8	8.1
Period, sec	4.1	3.4	11.1	9.2

The time histories presented in figure 6 indicate that the uncontrolled yawing motions were predominantly aperiodic. These motions are shown plotted in the same direction for convenience in comparison but were actually taken from motions to both the right and left. Most of the apparent divergence indicated by these time histories was caused by the slightly out-of-trim control settings previously mentioned. In addition to the effects of these out-of-trim control settings, the effect of random changes in trim is also indicated by the time histories of figure 6. These random changes in trim are attributed partly to movement of the controls caused by improper functioning of the servos and partly to the rather large random fluctuations in moments caused by propeller operation which have been observed in preliminary force tests of the model for the static-thrust condition. Because of these out-of-trim moments and random movements of the controls, the time histories of the yawing motions are too inconsistent to show clearly the stability of the model. The most reliable indication of the stability of the yawing motions was therefore obtained from the pilot's observations. These observations indicated that the yawing motions were about neutrally stable with perhaps a slight degree of stability for the rearward center-of-gravity location and a slight degree of instability for the forward center-of-gravity location.

The elevator and rudder control appeared very powerful since the model responded very quickly to control deflection. The model could be flown smoothly and easily with these controls despite the lack of stability. Inasmuch as the good controllability of the model more than offset the mild instability, the general flight behavior was considered reasonably satisfactory.

The vertical motions of the model were very stable because of the pronounced inverse variation of the thrust of propellers with axial speed. This vertical stability apparently offset the effect of the time lag in the thrust control so that the model could be maintained at a given height fairly easily.

Motion pictures of several flights of the model in the configurations discussed herein are available on loan from the NACA Headquarters, Washington, D. C. The results of this investigation are illustrated more graphically by the flight scenes of this motion picture than is possible in the present paper.

CONCLUDING REMARKS

The following results were obtained from preliminary hovering flight tests of the vertically rising airplane model in still air and away from the interference effects of the ground and side walls:

1. The uncontrolled pitching motions consisted of an unstable oscillation which was more unstable with the rearward than with the forward center-of-gravity location.

2. The uncontrolled yawing motions were predominantly aperiodic and were about neutrally stable for both center-of-gravity locations.

3. The normal airplane controls operating in the slipstream were very powerful.

4. Since the controls of the model were powerful and the instability was moderate, the model could be flown smoothly and easily in controlled flight under the conditions of the present investigation.

5. The model was difficult to trim in hovering flight because of random trim changes, one cause of which was the rather large random

fluctuations in moments caused by propeller operation. These moment fluctuations were observed in preliminary force tests of the model in the static-thrust condition.

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TABLE I

GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight, lb	27.5
Wing:	
Rectangular plan form	
Flat-plate section (0.5 thick)	
Aspect ratio	5.00
Area, sq in.	376.50
Span, in.	43.40
Chord, in.	8.68
Span of aileron, in.	15.67
Chord of aileron, in.	2.17
Over-all length of model, in.	55.00
Fuselage:	
Length, in.	44.00
Diameter, in.	6.00
Horizontal and vertical tails:	
Rectangular plan form	
Flat-plate section (0.25 thick)	
Aspect ratio	3.50
Area (horizontal or vertical total), sq in.	176.44
Span, in.	23.85
Chord, in.	7.10
Moment arm, distance from leading edge of wing to hinge line of controls, in.	30.37
Propellers:	
Eight-blade dual-rotating	
Diameter, in.	23.85
Hamilton Standard design, drawing number	3155-6-1.5
Solidity, one blade	0.031
Gap, in.	3.00
Moment arm, distance from leading edge of wing to center of gap between propellers, in.	14.50

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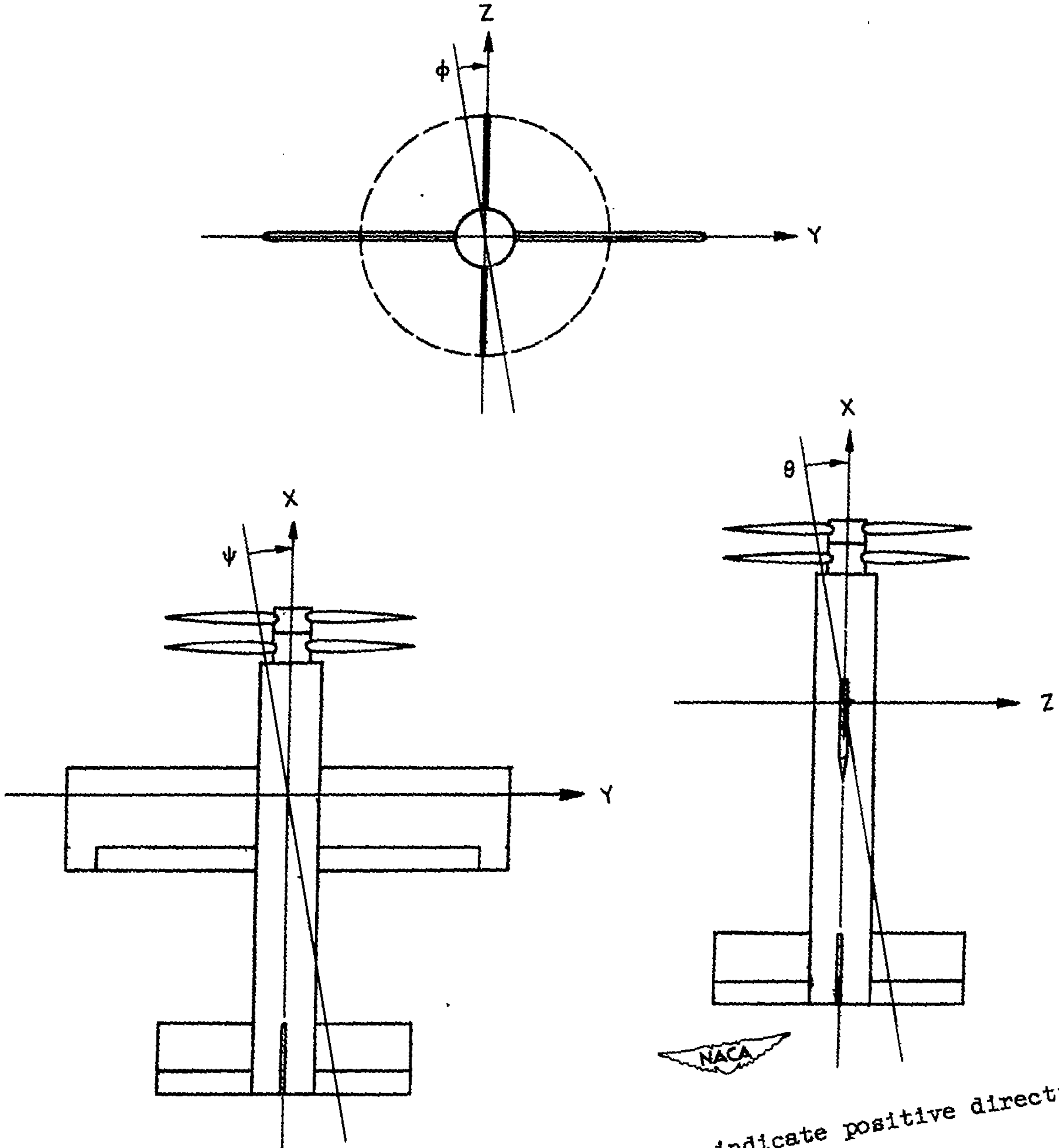

Figure 1.- The body system of axes. Arrows indicate positive directions of moments and forces.

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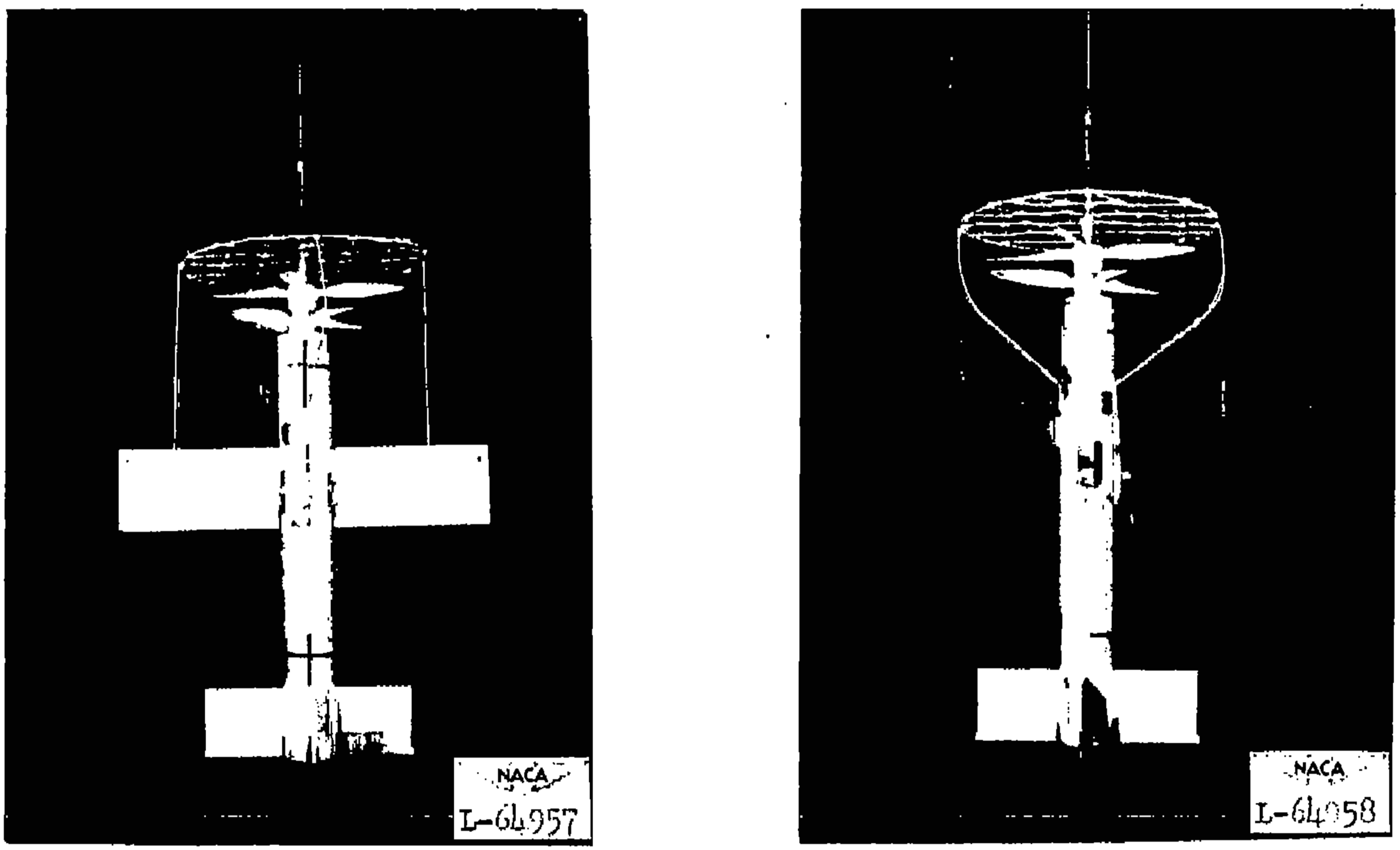

(a) Plan view.

(b) Side view.

Figure 2.- Photographs of the vertically rising model.

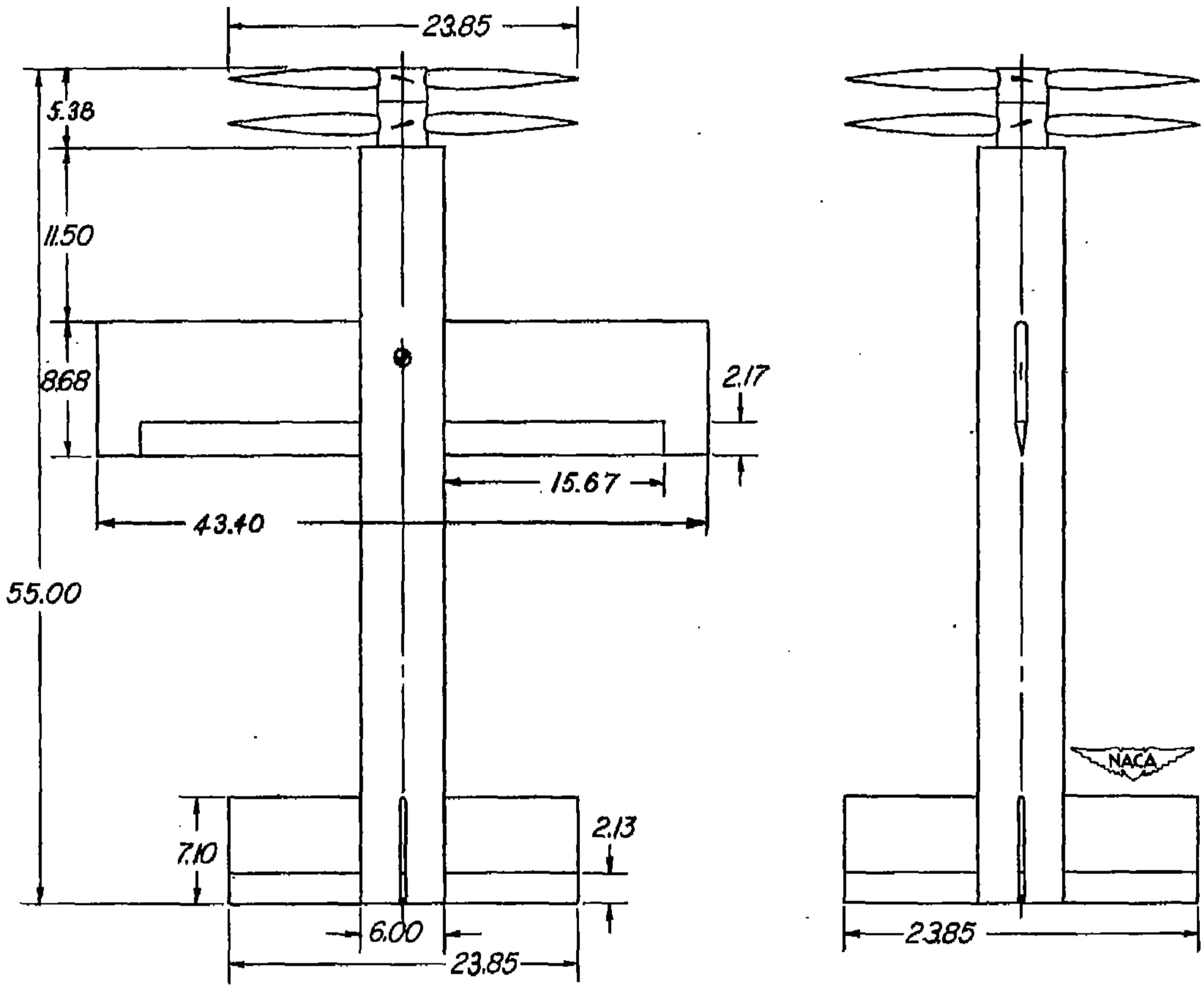

Figure 3.- Vertically rising model showing the important dimensions. All dimensions in inches.

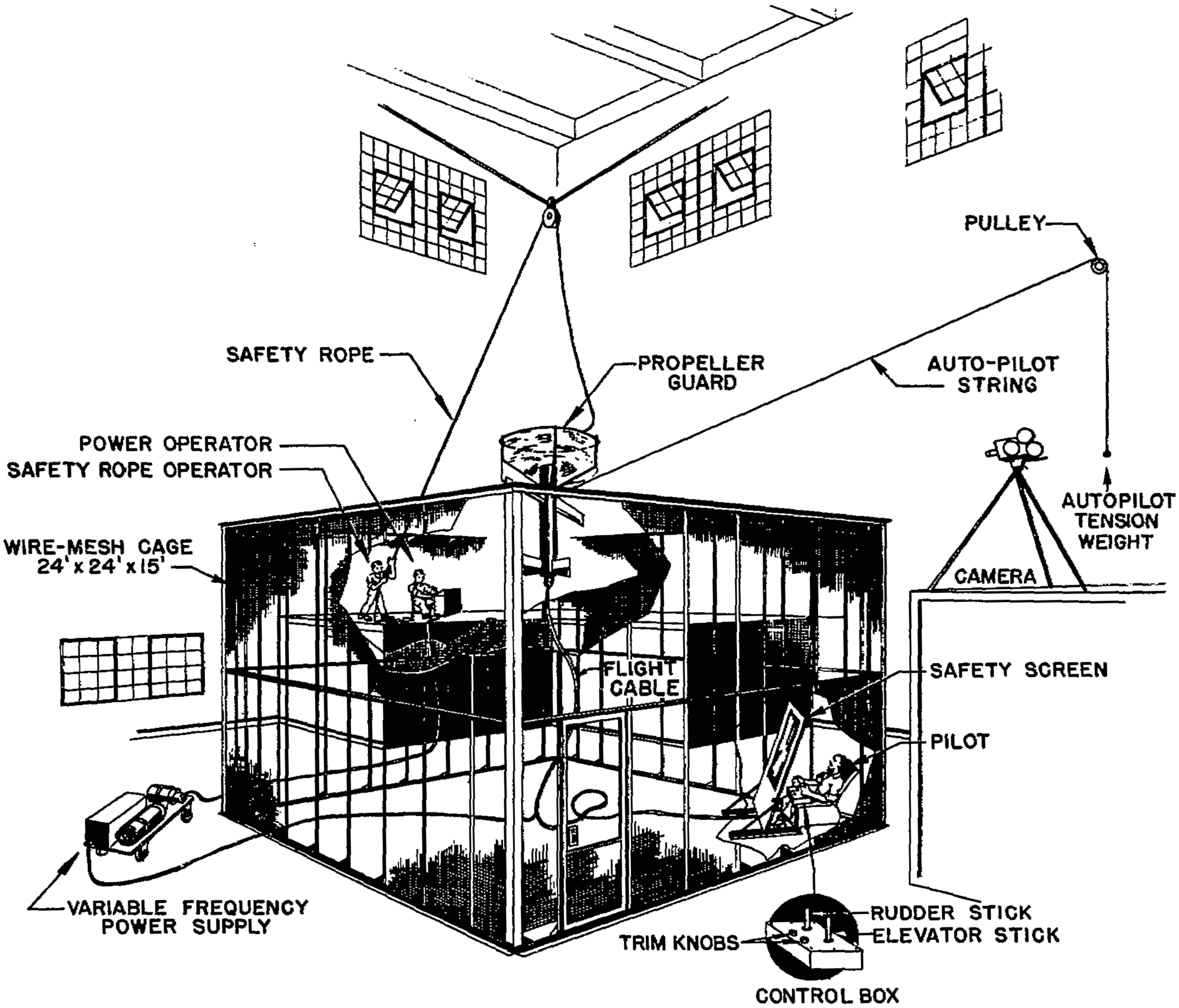

Figure 4.- Facility used for flight testing of hovering models.

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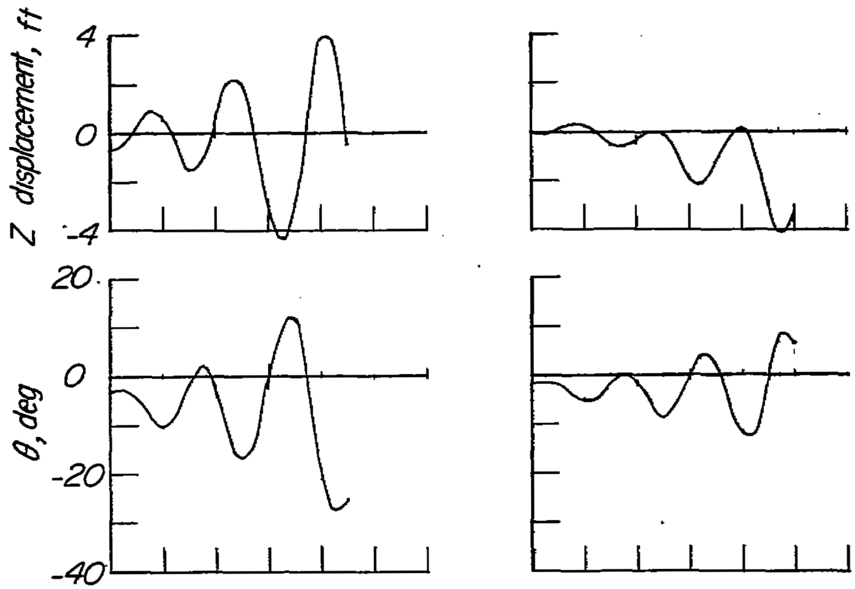
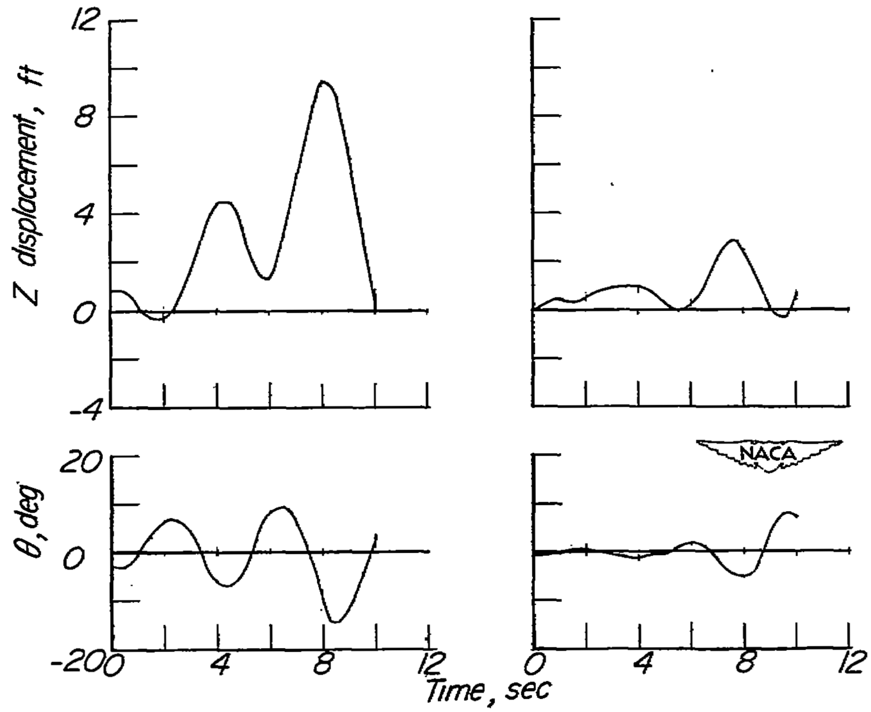
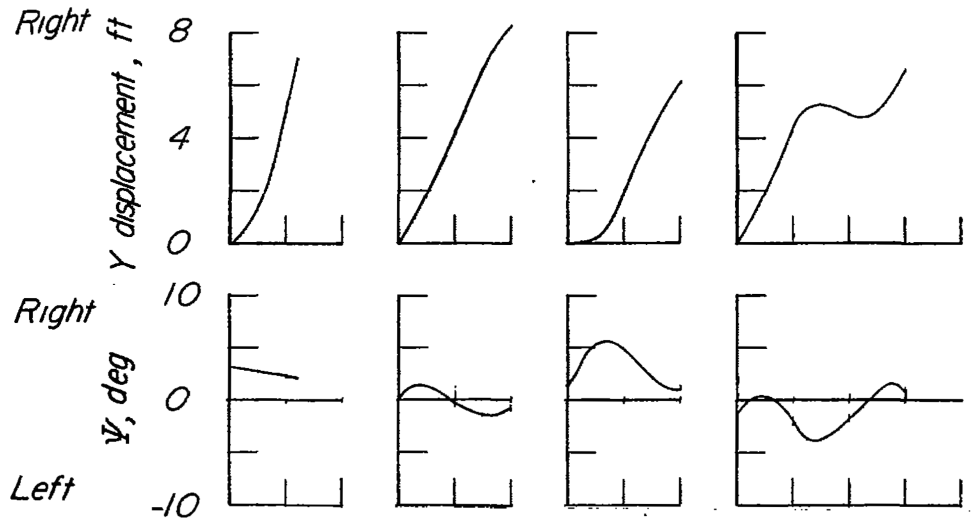


(a) Rearward center of gravity.

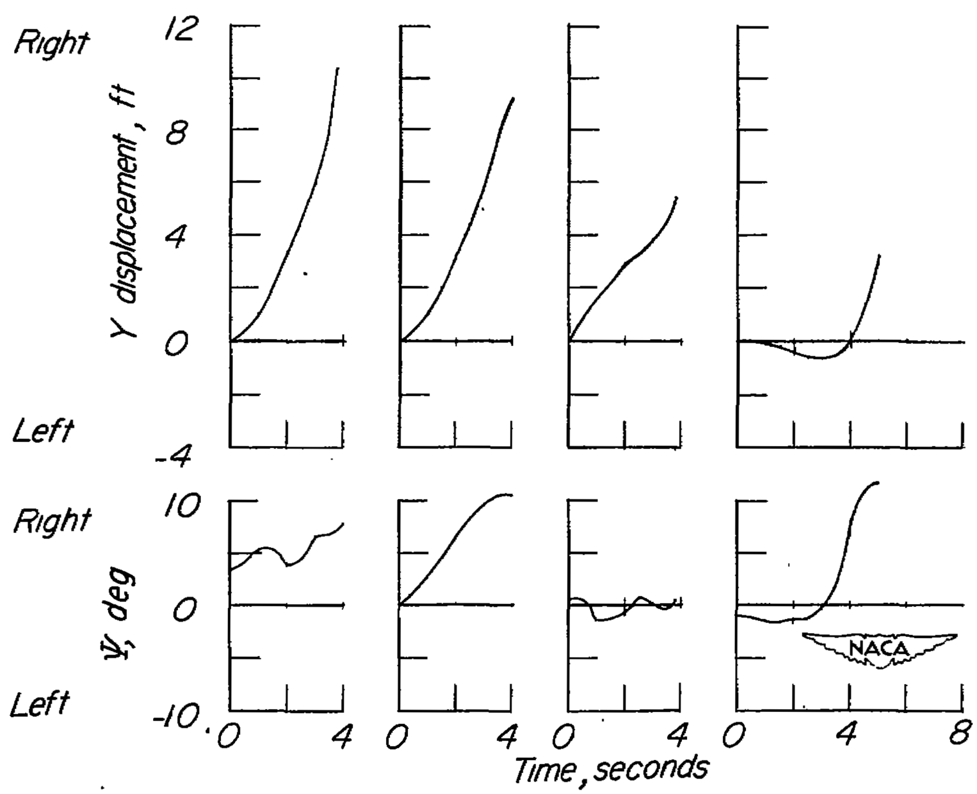


(b) Forward center of gravity.

Figure 5.- Uncontrolled pitching motions of the model.



(a) Rearward center of gravity.



(b) Forward center of gravity.

Figure 6.- Uncontrolled yawing motions of the model.